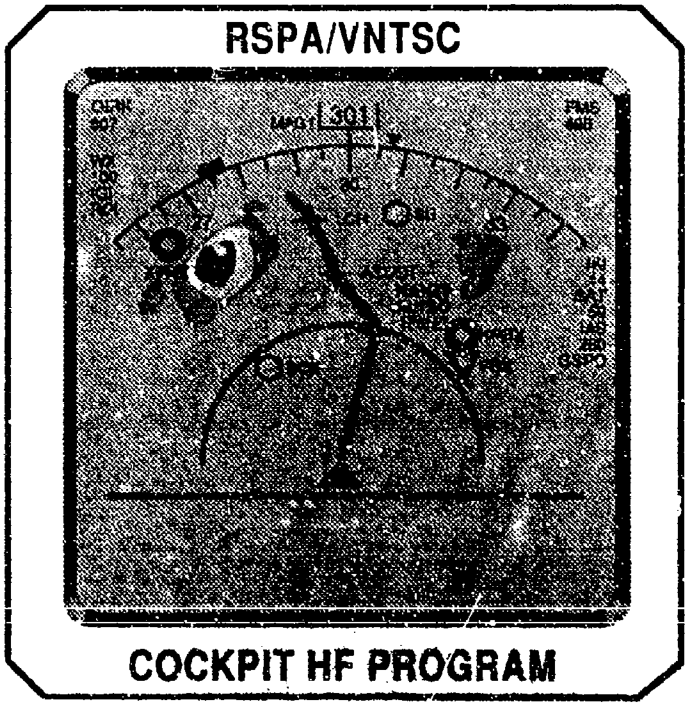
DOT/FAA/RD-93/4
DOT-VNTSC-FAA-93-3

Research and Development
Service
Washington, DC 20591

Determination of Loran-C/GPS Human Factors Issues



R. J. Adams
C. A. Adams
D. Eldredge
M. S. Huntley

U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe
National Transportation Systems Center
Cambridge, MA 02142

Final Report
April 1993

This document is available to the public through the National Technical Information Service, Spı.ngfield, Virginia 22161

U.S. Department of Transportation
Federal Aviation Administration

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 1993	FINAL REPORT Aug. 1992 - Mar. 1993

4. TITLE AND SUBTITLE

DETERMINATION OF LORAN-C/GPS HUMAN FACTORS ISSUES

5. FUNDING NUMBERS

FA3E2/A3093
C11547(2104)-1931

6. AUTHOR(S)

R.J. Adams, C.A. Adams, M.S. Huntley, and D. Eldredge

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Advancement Aviation Concepts Inc.
10356 Sandy Run Road
Jupiter, FL 33478

Volpe National Transportation Systems Center
Kendall Square
Cambridge, MA 02142

Battelle Memorial Institute, 505 King Ave., Columbus OH 43201

8. PERFORMING ORGANIZATION REPORT NUMBER

DOT-VNTSC-FAA-93-3

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Department of Transportation
Federal Aviation Administration
Research and Development Service
Washington, DC 20591

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

DOT/FAA/RD-93/4

11. SUPPLEMENTARY NOTES

Managed through the Cockpit Human Factors Program, Volpe Center

12a. DISTRIBUTION/AVAILABILITY STATEMENT

This document is available to the public through the National Technical Information Service, Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Discussions were held with a variety of private, Coast Guard, and off shore airplane and helicopter pilots who use Loran-C for navigation. These discussions revealed a number of problems concerning the design and use of the controls and displays of Loran-C receivers. The results are also relevant to GPS receivers that have many operational characteristics in common with Loran.

93-14819

93 6 29 07 1

36P8

14. SUBJECT TERMS	15. NUMBER OF PAGES
Loran-C, GPS, Human Factors, User Survey	40
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

PREFACE

This report identifies human factors issues and problems that general aviation pilots have using Loran-C navigation systems in the National Airspace System (NAS). The issues discussed include system design, software logic, handbook and training problems. Data was collected from group discussions with active pilots throughout the eastern United States and Canada during late 1991 and the first half of 1992. These discussions included air carrier, air taxi, corporate, business and pleasure users of Loran-C and a limited number of GPS users. The purpose of this study was to anticipate the potential human factor problems that could be expected in the full integration of GPS into the NAS. Since the use of Loran-C and GPS for navigation is very similar from the pilot's point of view, the problems described, the nature of the impact of each problem and the recommended solutions should provide system designers, manufacturers, and regulators with the information necessary to formulate future actions.

The material presented in this report would not have been possible without the project direction and conceptual support of Dr. Stephen Huntley of the DOT's Volpe National Transportation Systems Center. Dr. Huntley's extensive background in human factors research, knowledge of digital systems design, and first hand experience in flying these systems in the NAS were crucial to the completion of this research in a timely and cost effective manner.

In addition, Mr. Donald Eldredge of the Battelle Memorial Institute assisted in the early development and formulation of the method of approach for this research. Mr. Eldredge was encouraging and helpful in organizing and sorting out the important details of the human factors problems identified, acted in a critical technical review capacity and provided the necessary sounding board when data analysis difficulties were encountered.

Finally, and most importantly, the results presented in this report would not have been possible without the complete and timely support from the pilots, the flying clubs, the corporations, and the government agencies who agreed to participate. Their contributions are noted throughout the report both by organization name and by the quality of the results obtained. Although specific problems or concerns are not tied to specific individuals, each will recognize the presence and impact of their contributions.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2 = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2 = 0.09 square meter (m_2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (1)
1 pint (pt) = 0.47 liter (1)
1 quart (qt) = 0.96 liter (1)
1 gallon (gal) = 3.8 liters (1)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

$[(x-32)(5/9)]\ ^{o}F = y\ ^{o}C$

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yeards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliters (ml) = 0.03 fluid ounce (fl oz)
1 liter (1) = 2.1 pints (pt)
1 liter (1) = 1.06 quarts (qt)
1 liter (1) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

$[(9/5)\ y + 32]\ ^{o}C = x\ ^{o}F$

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0			1		2			3			4			5			6			7			8		9	10
CENTIMETERS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	25.40

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

^{o}F	-40^{o}	-22^{o}	-4^{o}	14^{o}	32^{o}	50^{o}	68^{o}	86^{o}	104^{o}	122^{o}	140^{o}	158^{o}	176^{o}	194^{o}	212^{o}
^{o}C	-40^{o}	-30^{o}	-20^{o}	-10^{o}	0^{o}	10^{o}	20^{o}	30^{o}	40^{o}	50^{o}	60^{o}	70^{o}	80^{o}	90^{o}	100^{o}

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

TABLE OF CONTENTS

1. INTRODUCTION

This work was conducted to identify and anticipate human factors problems associated with the use of GPS in typical aviation operations. The use of Loran-C and GPS for navigation is very similar from the pilot's point of view. Therefore, the study of current Loran-C operations provides a useful means of anticipating many human factors problems that may be encountered in the use of GPS navigation systems. The output of this research can also be used to assess the need for development of design guidelines or standards to address the issues identified.

1.1 Background

This project relied on the use of focus sessions to gather pilot opinions on the ease and accuracy of using Loran-C or GPS. Discussions were conducted with active pilots, pilot associations, and commercial operators to identify typical problems associated with the use of Loran-C or GPS. The focus sessions were scheduled to integrate currently planned meetings such as monthly flying club meetings with the data collection schedule. The groups interviewed included: general aviation flying clubs and private pilots, offshore helicopter operators, one air carrier, one corporate operator, and two search and rescue operators (USCG and Civil Air Patrol). Seventy-seven individual pilots were interviewed. Operational practices, problems and limitations in the use of Loran-C and GPS were identified through focused discussions and a written, single page, five question survey.

1.2 Purpose

The purpose of this research was to identify human factors issues in the use of Loran-C as a means of anticipating problems that could arise in the use of GPS navigation systems for aviation operations in the National Airspace System. This research should also lead to potential solutions in the areas of receiver design, software logic and training requirements.

1.3 Scope

This work was a nine month level of effort. Problem definition and data collection were initiated in October of 1991. Nine specific interviews were conducted between that time and April 11, 1992. The Loran-C/GPS users interviewed included pilots from:

- Reeve Aleutian Airways
- Petroleum Helicopters, Inc.
- United States Coast Guard
- Fareshares Corporation
- Florida Aero Club
- Civil Air Patrol (Lantana, FL squadron)
- Aero Club of New England
- Lakeland Sun 'N Fun fly-in pilots (two pilot groups)

1.4 Data Collection Procedures

The primary source of data was discussion sessions with groups of pilots. The procedures used consisted of a three-step data collection process:

- Definition of candidate data sources
- Development of data collection tools and procedures
- Specification of meeting (focus session) format and interview process

To insure that a consistent set of data was obtained from each pilot group, a project summary and list of topics for discussion were mailed out to prospective participants. Each participant was asked to fill out a brief Operational Usage and Problems Survey. These surveys primed the pilots for the group discussions in the areas of:

1. How pilots normally use Loran-C
2. The most frequent problems pilots experience using Loran-C
3. What system design features or functions are used most frequently
4. What system design features are never used and why
5. The major pilot/system interface concerns

To insure that the interview process was time efficient, yet comprehensive, a list of 52 interview questions was used by the facilitators to guide the discussions. The results of each interview/data collection meeting were summarized in written reports based on pilot opinions expressed during the discussions. These results form the foundation for the analysis of Loran-C/GPS human factors problems, as well as, the conclusions and recommendations presented in the remainder of this report.

1.5 Summary of User Problems and Issues

The results of these discussions indicate significant *under-utilization* of Loran-C and GPS system capabilities and the *potential for human errors* induced by either the receiver design, the software logic or the lack of sufficient knowledge and training in system operation. Based on the pilot discussions, the following results and key problems are critical to the future safe use of Loran-C and GPS as well as the integration of these systems into the National Airspace System (NAS).

Several problems identified during this study were common to all pilots interviewed regardless of: the number of years experience (both total flying time and Loran-C system experience), the operational requirements (types of routes, procedures, etc.), type of aircraft flown (helicopter, single engine or multi-engine airplane, piston or turbojet), or, the pilot qualifications. These included:

1. Pilots rely on Loran-C primarily for point-to-point navigation using the pre-stored data base of three and five letter identifiers. for airports, VORs, NDBs, intersections, etc. They do not typically use latitude/longitude input capability. The routes used consist of two to

three waypoints even when navigating the entire east coast of the U. S., New York to Florida.

2. The pilots interviewed could not use the full range of functional capabilities due to: the complexity of system operation (i.e., the non-intuitive, multi-function knobs); the lack of available training; and, deficiencies of the manuals provided by the manufacturers.

3. Although the Part 135 offshore operators and the Coast Guard use their Loran-C systems for approaches and are confident in this capability, the rest of the pilots interviewed did not feel comfortable using Loran-C as an approach aid.

4. Automation induced tunnel vision is trickling down to general aviation from the airlines. Reliance upon the Loran-C, GPS or navigation management system becomes so ingrained, that blunders, warnings, alerts, and signal drop-outs often go unnoticed.

5. Because of the expense and safety implications of trying to learn the system while flying, pilots are not familiar with many of the system's features.

The problem with this typical use of Loran-C is a basic dependence on the one hand but a lack of knowledge and understanding of system operation and capability on the other. This situation has been frustrating to pilots as reported in the subsequent discussion. More importantly, this situation puts the pilots and their passengers at risk when something does go wrong, or when a programming change is required due to an amended air traffic control clearance or weather.

The following key problems are provided as an overview of the pilot opinions and concerns based on their experience using Loran-C (and limited GPS) in normal operations within the NAS. The problems are summarized in three basic categories: System Design, Software Logic, and Training. Each of these areas require considerable attention to reduce human error potential in future operations.

1.5.1 System Design Problems

There were three basic pilot problems in this area:

1. The various functions of multi-function knobs, keys or switches are difficult to learn, hard to remember and cause errors.

2. The lack of standardization of basic functions among receivers increases workload inflight and training time pre-flight.

3. System lock-up problems are not adequately annunciated.

A detailed explanation of each of these problems, the nature of the impact of the problem and the recommended solutions are presented in Section 2.1

1.5.2 Software Logic Problems

The complexity of operating procedures prevented pilots from using full system capabilities. The following nine major problems were expressed by the pilots interviewed:

1. The organization of procedures required to execute the various functions of the receivers is not intuitive or operations oriented.

2. Lack of reality checks on data entry allows large input errors to be accepted and used without warning.

3. Lack of prompting inhibits system utilization by new users, infrequent users, or rental aircraft users.

4. Correcting input errors or amending flight plan data inflight is time consuming.

5. Modifying flight plans to accomodate ATC re-routing is too complex for a single pilot operation.

6. The lack of an on-line help function reduces the use of Loran-C and GPS by pilots.

7. The complexity of software "upgrades" is a further deterrent to full use of system capabilities.

8. Difficulty in deselecting a Master Station has caused large aircraft position errors and lack of confidence in Loran-C.

9. The lack of pre-stored waypoints to circumvent controlled airspace increases both pilot and controller workload.

Section 2.2 provides a complete discussion of each problem including the impact on flight operations and recommended solution.

1.5.3 Handbook and Training Problems

Six specific problems identified were:

1. Operation manuals are often not availaable for pilots who rent aircraft, instructor/check pilots, and those who fly infrequently.

2. Manuals are not organized or formatted for ease of use by pilots.

3. Training tutorials are not available to facilitate pilot understanding of the system.

4. Instructors generally are not familiar with Loran-C and GPS system operation and cannot provide the necessary information to train pilots to safely operate the systems in the NAS.

5. Pilot training , familiarization and proficiency with Loran-C/GPS are inhibited when the units cannot be removed from the plane for home study.

6. Data base updates are not typically used by the pilots interviewed. This will become a serious problem if/when systems are approved for IFR or approach use.

The pilot's description of these problems, their impact, and the needed material and training are presented in Section 2.3.

1.6 Conclusions and Recommendations

A significant amount of work needs to be done in several areas if GPS implementation is to avoid the human factors errors and problems currently identified by pilots using Loran-C. First, in the area of system design, a comprehensive study and critical evaluation of multi-function knobs, keys, and switches needs to be performed to identify human memory limits, error frequency, error types, and workload limits by phase of flight. The results of such a study could be used to develop design guidelines or minimum operational performance standards for number of knobs, number of functions per knob, type of functions, and sequence of functions.

Second, a major re-design of system software logic and functional organization needs to be performed to make Loran-C or GPS systems pilot friendly and more intuitive to operate. The recommended organization would by by flight phase. The re-design should also include an examination of minimum data required and displayed for each phase of flight as well as consideration of on-screen prompts or a help function to improve the pilot's ability to operate the system with minimum workload and minimum reliance on memory.

Third, the predominant use of three letter identifiers to input Loran-C or GPS waypoints and routes suggests that an analysis of sectional charts, low altitude enroute charts and approach plates be performed to determine/evaluate the need for adding three letter identifiers to frequently used intersections, local fixes, etc. (i.e., those elements of the chart information for which three letter identifiers are not currently included).

Finally, manuals, handbooks and user's guides need to be reviewed for format and content. To be useful, the manuals must be written clearly and well organized. Standardization of the Table of Contents or outline for all systems is strongly recommended (like the standard aircraft flight manual outline). Second, there is a definite need for a checklist type of guide or Quick Reference Handbook (QRH) that stays with the aircraft. Third, avionics training should be a requirement. Avionics training and

qualification standards must be a developed, evaluated and implemented for both pilots and instructors to reduce the potential for human error and maintain the desired level of safety.

2. LORAN-C/GPS USERS

This section presents a brief characterization of the pilots interviewed, summarizes the types of routes and procedures flown and analyzes the functions of the systems which they normally rely on in their everyday flying. To begin this characterization, A summary of the Loran-C and GPS user groups interviewed, the systems they typically use and the aircraft they fly are presented in Table 1.

TABLE 1. LORAN-C AND GPS USERS INTERVIEWED

USER GROUP and Operating Area	SYSTEMS USED	TYPICAL AIRCRAFT
Reeve Aleutian Airways Alaska to Northwest, U. S.	ONI 7000 Loran-C TNL 788 GPS/Omega	B727-100
Petroleum Helicopters, Inc. Louisiana/Gulf of Mexico	TDL-711, KLN-88, ARNAV R50i	Bell 412SP, 212, 206L S-76, AS350, BO-105
United States Coast Guard Gulf of Mexico to the Caribbean	Collins ADL81 & ADL 82 (multi-sensor, Kalman filtered flight mgmt. sys.)	HU25A/B/C & HH65
Fareshares Corp. Connecticut/Northeast	II Morrow, Northstar M1	Piper Navajo, Westwind
Florida Aero Club Florida to Canada & New York to St. Louis	II Morrow, KLN-88, R-50i, R-20, R-15, Northstar M1, Magellan (GPS)	C152/172, Bonanza V-35, F-33A, PA-23, DG-400, C140, Meyers 200
Civil Air Patrol South Florida to the Everglades	Apollo 612B	Cessna 172
Aero Club of New England Northeastern U. S. to Canada and the Caribbean	ARNAV R-21, II Morrow, Northstar M1, Apollo II	C172, C201, Piper Arrow, BE Twin Otter, BE Baron (-55&-58), C421, PA-23
Lakeland Sun'N Fun Eastern half of U. S. to Canada	Azure, Terra 120, Northstar Apollo, R-30, II Morrow Foster F-14, Garmin (GPS)	C172, PA-135, Citabria, Piper Tri-Pacer, Bonanza, Taylorcraft, BE Baron

2.1 Description of General Aviation Loran-C/GPS Users

The pilots interviewed (77) were qualified, experienced individuals with 100 to 25,000 total hours (3750 average) and mature (32-80 years old). They use their aircraft for both business and personal travel and rely on Loran-C and GPS (4 users) for point-to-point navigation. About half of the pilots indicated they use the equipment as a secondary or back-up navigation system for the primary VOR/DME low altitude airways and direct area navigation routes while the other pilots used it as the primary navaid in Visual Meteorological Conditions (VMC). Their area of operation spanned the eastern half of the U. S. to the Bahamas in the southeast and

from Florida and the Gulf of Mexico to Long Island and Suffolk, New York in the Northeast U. S. and included Ontario to Montreal in Canada.

About one-half (45%) of the pilots flew IFR. Their average IFR total hours was 198. The aircraft flown varied from the Cessna 172 and the Navion on the low end to the Beech Baron and Cessna King Air categories as illustrated in Table 1. The type of Loran-C systems used included: the Apollo Flybuddy, the II Morrow 612 & 618, the ARNAV 20, 30, & 50i (with GPS Interface), the Northstar M1, and the KLN-88 and the King 8001 & SITEX marine systems. Although some of these systems represent first generation technology, software, and library capabilities, the operational issues and pilot perspectives on what they need to use a Loran-C or GPS navigation system will not change. The problems and needs discussed offer the designers and manufacturers the opportunity to enhance and refine their products as new models are introduced.

This group of pilots has become very accustomed to reliable and accurate Loran-C information and depend upon it for both normal (e.g., point-to-point navigation, controlled airspace alerts, etc.) and emergency (e.g., nearest airport) information. As stated by one pilot: "Because it is so reliable normally, Loran-C can easily create pilot dependency and complacency," (Appendix B, number 1). However, this user group expressed frustration and confusion in trying to utilize full system capabilityies, understand and apply information in the owners manuals. For example, pilots complained:

"On our Loran-C set, you have to get too engrossed in the instrument for simple functions, i.e., change/enter waypoints," (Appendix B, number 2).

"Pilots spending too much time inside playing with the Loran when they should be looking for other traffic," (Appendix B, number 3).

"On some models a doctorate degree in computer programming is handy," (Appendix B, number 4).

"Manuals are too technically oriented for most pilots' interest. Too much what and why, not enough 'how to'. Manuals appear to be written by technicians rather than users," (Appendix B, number 5).

As a result of these difficulties pilots used only the most basic functional capabilities of the systems, but all realized there was a wealth of untapped information.

2.2 Functions Normally Used

In general, the pilots interviewed used the pre-stored data and three letter identifiers (when available) to define fairly simple routes (2-3 waypoints) and relied on the Loran-C or GPS system for point-to-point navigation. These pilots were not familiar with many of the other functions or capabilities of their systems, did not attempt to

input user defined waypoints (Latitude/Longitude or Rho/Theta input), did not typically use the flight plan mode, and in general were dissatisfied with the user's manual and system operation handbooks supplied by the manufacturer of the systems.

There was an obvious correlation between the quality of the instructional information (input/output, functional, and diagnostic instructions, etc.) and the ability of the general aviation pilots to use the systems to there fullest capability. This was especially evident between the average pilot interviewed who reported spending one to two weeks with the user's manual (self-study) prior to using it inflight and the USCG pilots who receive about 24 hours of avionics classroom instruction.

The functions typically relied upon by most of the general aviation pilots interviewed were:

1. Distance and bearing
2. Course deviation indication
3. Time and groundspeed
4. Estimated time enroute (ETE)
5. Position reading/reporting
6. Inflight calculations of true airspeed, groundspeed

The better trained pilots and those with more demanding operational requirements (USCG and Offshore Oil Operators) realised more of the capabilities of their equipment and reported use of the following functions:

1. User defined waypoints
2. Time between waypoints.
3. Parallel offset for approaches [OSAPs[1]]
4. Programming [waypoints]
5. Increase sensitivity [for OSAPs] and approaches
6. Course parallel offset
7. Next leg data
8. Winds aloft calculations [compare to forecast]
9. Flight planning mode

The next section enumerates and discusses the specific problems that pilots experienced in using the Loran-C or GPS systems.

---

[1] OSAP - Offshore Standard Approach Procedure. See Appendix A for an example approach plate.

3. USER PROBLEMS AND ISSUES

The following human factors issues are those issues which system designers, manufacturers and regulators should consider as critical for two reasons. First, active pilots identified these issues as major problems or concerns which they felt needed improvement in future designs for either Loran-C or GPS. Second, the resolution of these issues may be critical to the use of these systems in the next generation national airspace system.

3.1 System Design Problems

3.1.1 Multi-Function Knobs, Keys or Switches

Problem Statement: The functions of multi-function knobs, keys or switches are difficult to learn, hard to remember and cause errors.

Discussion: Pilots reported problems using the multi-input functions associated with single input devices (e. g., keys, knobs, etc.). First, the multiple functions are not intuitive or easy to learn using existing system manuals. One pilot reported: "Unlabeled, multi-function knobs are confusing and the multiple uses easily forgotten," (Appendix B, number 6). An example of this problem is the "TO" button used to select airport information on some systems. Second, multiple strokes of the same key causing different results has caused input errors in turbulence or during periods of high workload. For example, on one system depressing the CLR (clear) key one time erases the last letter or number entered, but depressing it twice in succession erases the whole display. Another pilot reported: "The three knobs on my system have 18 combinations of ways to use them," (Appendix B, number 7).

The complexity of system operation was a general criticism along with the need to re-learn the multiple functions after a brief one to two weeks without flying. This pilot observation has been substantiated in aviation research which has shown that fundamental flying skills (psychomotor) are retained over time even without frequent use, but procedural and knowledge dependent skills are less easily retained.

Nature of Impact: The major impact of this problem is reduced safety. The current complexity of system operation caused by the use of unlabeled, multi-function knobs, keys, or switches requires too much head-down time and mental workload. This burden detracts from flying the airplane and looking out for other aircraft. Combined with the possibility of inadvertent erasing of data (on some systems) and the difficulty of retention of system operation skills, this fact will cause even more problems and errors as the use of Loran-C and GPS is expanded to instrument operations and possibly approach procedures.

Recommended Solution: System design guidelines and minimum operational performance standards should be developed. This development will require specific research on human performance capabilities and limits for: number of knobs, number of

functions per knob, types of functions that can be logically combined (from a pilot's perspective), and the acceptable sequence of functions.

3.1.2 Lack of Standardization

Problem Statement: The lack of basic standardization among receivers increases workload inflight and training time.

Discussion: Most pilots did not like the lack of standardization for even the most basic items between systems. One pilot asked: "Why can't the basic direction of the ON/OFF switch or knob be common between systems?" (Appendix B, number 8). Other pilots expressed similar concerns for the result of clockwise versus counter clockwise slewing and the order of displaying airport, VOR, NDB, intersection, nearest airport, etc. Still others reported a need for standardization of the minimum data displayed on one page. The lack of such standardization has caused pilots to either not use the system (because they forgot how or were renting an aircraft with an unfamiliar system) or to learn while flying.

Nature of Impact: This problem area has caused input errors and can cause operator-induced navigation errors. The lack of standardization has lead to higher workload in the best circumstances and to deviation from the desired route in others. Since piloting an aircraft is a multi-task function, and since pilots are trained to rely on standard procedures which lead to desired results, the current lack of limited standards for some basic design features is a serious concern.

Recommended Solution: Manufacturers, researchers and regulators should jointly re-evaluate the current published Minimum Operational Performance Standards and Advisory Circular material for both Loran-C and GPS. Although a large number of systems are currently in use and may have to be accepted by a grandfather clause, the next generation of systems (primarily multi-sensor and GPS) will be around for 20-50 years.

3.1.3 Alerts and Warnings

Problem Statement: System lock-up problems are not adequately annunciated.
Discussion: Pilots have reported three separate problems related to lack of sufficient alerts or warnings when the Loran-C systems lock up. They are: 1) with current alerts and warnings errors are not readily detectable, 2) position errors occur due to lack of cross-checking, or, 3) pilots misinterpret a CDI which stays centered as their own precise flying. The use of subtle alerts like a frozen display, blinking display, yellow or red warning lights are not adequate due to the fact that the Loran-C display is generally located outside the pilot's normal scan. Therefore, noticing and responding to these alerts has taken pilots from one to four minutes and result in deviations from the desired track. Even a frozen CDI or an unchanging ETE/GS display takes some time to get the attention of a pilot due to his other workload. The same problems would occur when GPS locks up due to insufficient satellites for determining position, inadequate geometry to meet the position calculation limits or when satellite malfunctions occur.

Nature of Impact: The primary impact, to date, has been enroute position errors, momentary disorientation when the errors were discovered and minor time inconveniences. However, in the future NAS, and in the use of these systems for instrument operations or operations in congested terminal area maneuvering, there may be a significant safety or protected airspace impact.

Recommended Solution: The near-term problems can be mitigated by formal and/or required training in the procedures recommended by the manufacturers for detection and resolution of the lock-up problems. For new designs, pilots were not satisfied even with the flashing alert lights and stated: "Warning indicators must be adequate to attract the pilot's attention and prevent deviations," (Appendix B, number 9). The addition of an aural warning and/or a flag on the CDI are suggested alternatives.

3.2 Software Logic Problems

3.2.1 Software/Function Organization

Problem Statement: Software/function organization is not intuitive or operations oriented.

Discussion: Pilots did not like the sequence of pages (e.g., NAV-1...NAV-8) on most systems. The organization of the pages and the data displayed on each page was not intuitive. That is, the pilots had to search for the page containing the information they desired and often use more than one page to obtain all the data they wanted (e.g., DTG, CTD, ETE, TRK, etc.). Pure memorization of page sequence and display contents for each page was required as opposed to a logical or pilot-friendly design. One pilot provided the following written description: "Selecting the correct mode of operation on this unit is a problem in that it is difficult to remember which page of this massive system contains the information you need. Once you find the correct page, you must remember (or look up) the correct data entry sequence. And in most cases, as with other such modal programs, making a mistake means starting over from the beginning. You'd think programmers had never heard of a backspace key," (Appendix B, number 10).

Nature of Impact: The basic impact of this software organization problem is that pilot's do not use the systems to the full capability available. This result stems from the lack of adequate information or poor organization of the manuals provided as well as the lack of availability of any formal training. Software organization, display content and information retrieval will become increasingly important to operations in the NAS as VOR/DME enroute navigation and ILS approaches are replaced by grid coordinate systems such as Loran-C and GPS.

Recommended Solution: Software design guidelines and minimum functional requirements that address these problems need to be established. This should include a projection of the operational requirements for the pilots and the navigation systems in the future NAS. One recommended organization would be by flight phase or event. Also, an

analysis should be conducted to determine the requirements for user friendly functions such as: a backspace or delete key, a help function, on-screen prompting for system start-up and flight planning, an escape function which would negate any action taken which erroneously changes current navigation parameters, etc.

3.2.2 Lack of Reality Checks on Inputs

Problem Statement: Lack of reality checks on data entry allows large input errors to be accepted and used without warning.

Discussion: Most of the systems in use do not have basic latitude/longitude magnitude and direction (N/S, E/W) mathematical crosschecks or input limitations. As one pilot said: "The system will accept any error you input. For example, you can input 911 degrees longitude and it will accurately calculate a course to this nonexistent position. You can also enter up to 99 degrees magnetic deviation and it will accept it," (Appendix B, number 11). This can introduce large errors in navigation and guidance information, including the complete reversal of latitude with longitude. This would be such a simple software check that the pilots could not understand why the systems would be designed in this manner.

Nature of Impact: The major impact of the lack of input data cross-checks is large data entry errors. These are normally detected quickly by the pilot due to the extreme values for distance-to-go, estimated-time-enroute, crosstrack error, etc. which are displayed after the erroneous input is accepted. However, the time spent in re-programming, the potential for these errors to go unnoticed until airborne and trying to capture a route, and the potential safety impact all indicate that elimination of this type of problem would be worth the effort and cost.

Recommended Solution: At the very least, basic hemisphere limits should be used to constrain input errors. If feasible, independent, corroborating information should be used to cross-check input data. Future systems using multi-sensor inputs and/or combinations of information from independent sources could rectify this problem.

3.2.3 Lack of Prompting

Problem Statement: Lack of prompting inhibits system utilization by new users, infrequent users, or rental aircraft users.

Discussion: Pilots are intimidated by the amount of information available and the complexity of retrieving and using the information. One pilot complained: "Such a vast amount of information is available that the full extent of the system is very difficult to learn and use," (Appendix B, number 12). Other pilots stated: "One or two weeks without flying requires re-learning how to use the system. Some on-screen help would increase the usability of these systems," (Appendix B, number 13).

Nature of Impact: The impact of this problem is twofold. First, the lack of prompting discourages the use of Loran-C or GPS and second it can results in high workload and time

consuming input which is not necessary. The combination of lack of system familiarity and lack of prompting also invites input errors for infrequent users.

Recommended Solution: Manufacturers should consider the marketing advantage of a system which provides on-line prompting versus the minimal technical effort and cost involved with its implementation. On-screen prompts for system start-up, waypoint input, and a general help function to improve the pilot's ability to operate the system with minimum workload or reliance on memory would increase and enhance system usage.

3.2.4 Correcting Errors or Reprogramming Systems Inflight

Problem Statement: Correcting input errors or amending flight plan data inflight is too difficult and time consuming.

Discussion: Several pilots complained that correcting input errors or making flight plan changes with their systems required a complete reprogramming (i.e., erasing all associated data and starting over). This process is not only time consuming, but error prone. It also leaves the pilot in a heading hold or dead reckoning mode of navigation if the Loran-C is the only navigation system currently being used. As one pilot clearly stated, "My major concern are the complex procedures for entering waypoints and the head-down time which elapses when programming a new waypoint designation," (Appendix B, number 14).

Nature of Impact: The major impact of this problem is to cause too high a workload for what should be a simple, common input task. Depending on the time and phase of flight (i.e., the other pilot workload demands), this problem could impact safety of flight. The systems which have this problem may not be suitable for use during terminal operations in high density areas or during instrument approaches due to the frequency of route changes and runway changes in these operations.

Recommended Solution: Single character correction capability should be possible without affecting the balance of data (i.e., back-space or single character delete key). Desired flight plan changes should be inputable between two pre-existing waypoints and the remaining, unused fixes should ratchet down in the active list.

3.2.5 Modifying Flight Plans to Accomodate ATC Change in Route

Problem Statement: Modification of programmed routes in flight is too difficult for a single pilot operation.

Discussion: The pilots felt that inputting any ATC rerouting from pre-programmed Loran-C route data was too complex. The workload associated with remembering which page the data was on, or scrolling to the appropriate intersection, NDB, or VOR, or finding the Latitude/Longitude for the fix (from a facility directory) and inputting it correctly was too time consuming. The number of steps required to acquire the needed information, input

it, verify the input, and have confidence that the guidance provided by the Loran-C is correct requires too much head-down time for a single pilot operation.

Nature of Impact: The major impact of this problem is in the integration of Loran-C into the ATC system which is currently based on VORs, airways, intersections, etc. Although pilots can operate in both systems, the ease of use and timeliness of responding to ATC course changes is currently much less workload using the VOR system. Therefore, pilots revert to VOR/DME navigation when ATC changes are required.

Recommended Solution: A major step toward reducing the impact of this problem would be to include latitude/longitude data on route charts. A second recommendation would be to organize and present VOR, NDB, intersection, and airport data on the systems as a function of geographic region or distance from the facility. In this manner, when changes occurred in an area of operation, all necessary identifiers and their locations would be grouped for easy retrieval and use.

3.2.6 Lack of On-line Help

Problem Statement: The lack of an on-line help function reduces the use of Loran-C and GPS by pilots.

Discussion: The vast majority of the pilots interviewed complained that the Loran-C system operation was too difficult to learn initially and impossible to remember when the systems were not used frequently (ed. about weekly). They felt that the provision of an on-line help function to aid in the use of the system (i.e., finding the page with the CDI, looking for airport information, going back to the navigation page, and verifying where the DTG and ETE numbers were going to) would be an important improvement. Basically, they expressed a need for help navigating within the Loran-C system to get the information they wanted when they needed it.

Nature of Impact: The major impact of the lack of on-line help is decreased usage of the Loran-C systems. FBOs who rent aircraft do not always have the Loran-C handbook or user's manual Instructors and check pilots have to operate a number of different systems and cannot easily remember the nuances of each system architecture. Pilots who rent aircraft and are familiar with Loran-C and want to use it are limited by all of the above problems.

Recommended Solution: The manufacturer's and regulators should determine the need for on-line help functions. This effort should be accompanied with the analysis of the need for limited standardization, the re-evaluation of the minimum operational performance standards and the need for standardized checklist or quick reference handbooks.

3.2.7 Complexity of Software Upgrades

Problem Statement: The Complexity of software upgrades is a further deterrent to full use of system capabilities.

Discussion: Pilots expressed difficulties in keeping up with the frequency and detail of the manufacturers software changes. One pilot reported that he had received three software upgrades in two years and each one was more difficult to learn since: "The manuals do not always keep pace with the software updates," (Appendix B, number 15). Another pilot reported that updating has caused problems in his use of the system due to subtle changes in location of discrete data within the software. In both cases, the pilots felt that the systems were not as easy to use after the upgrades as they were before. They said that the changes "were not made by someone who was familiar with how the systems were used," (Appendix B, number 16).

Nature of Impact: Decreased usage of the systems and lost confidence in ability to use the system for conventional operations were the two impacts related by the pilots. Basically, this is a manual, training, and frequency of use problem.

Recommended Solution: Manufacturers should consider self-regulation in this area. They should limit the number and frequency of software changes to something that they feel the user community could accommodate without major disruption in use of their systems. The self-regulation should also include providing timely, clearly written, and operationally useful manual changes to support the understanding and use of the software changes.

3.2.8 Difficulty in Deselecting a Master Station

Problem Statement: Difficulty in deselecting a Master Station has caused large aircraft position errors and lack of confidence in Loran-C.

Discussion: The pilots operating on the east coast from New York and Florida have experienced difficulties operating in proximity to Seneca in the north and Jupiter in the south. Consistent problems with accuracy have been experienced enroute (5-7 mile errors) to the extent that none of the pilots considered Loran-C as a viable approach system. The general feeling was "five miles accuracy enroute is fine, but, not reasonable for terminal area or approach use," (Appendix B, number 17). Interviewed pilots expressed the difficulty of deselecting a Master station, such as Jupiter, to improve accuracy.

Nature of Impact: The most noticeable impact of this problem is large actual position errors caused by Loran-C position calculation errors when operating on the baseline extension of a Master Station. Pilots experiencing these errors did not understand the problem and did not know how to deselect the Master Station in use and navigate using a different triad. One pilot was disturbed enough by the frequency of occurrence of these large errors that he went to his FBO and had them fix the problem. He now does not know how to re-input Jupiter as a usable Master when the geometry is favorable.

Recommended Solution: Simplified procedures to deselect should be developed and prominently identified in all users manuals, checklists, etc. The training material should clearly define the Baseline extension problem, when to expect it, and how to resolve it for each system user. For GPS systems, the analogous bad geometry errors or satellite dropping below the horizon, should be similarly identified and procedures for reconfiguring the navigation system developed and defined for the pilot's use.

3.2.9 Additional Library Data Needs

Problem Statement: The lack of pre-stored (Loran-C or GPS system library) waypoints to circumvent controlled airspace increases both pilot and controller workload.

Discussion: The current controlled airspace warnings and alerts are useful to the pilots as far as they go. However, the pilots suggested that two additional types of information would further reduce workload. First, they would like the systems to identify the type of controlled airspace (i.e., ARSA, TCA, MOA, etc). Second, they would like to have the systems provide suggested waypoints or fixes for use in circumnavigating the controlled airspace.

Nature of Impact: The lack of these pre-stored fixes and the identification of the type of airspace causes increased pilot workload in navigating around the airspace. The pilot must either use his chart or contact ATC to develop alternate routing. Input the new routing into his Loran-C or GPS and/or use heading vectors to circumnavigate the controlled airspace and then recapture his desired course.

Recommended Solution: Investigate the feasibility of providing these types of navigation fixes. VOR locations, Cardinal Radials off of local VORs and DME distances, etc., could be used and converted to latitude/longitude waypoint data to be used by the Loran-C or GPS user. If feasible, these waypoints should be included in the system library of pre-stored data.

3.3 Handbook and Training Problems

3.3.1 Lack of Operating Instructions

Problem Statement: Operating instructions are often not with the aircraft. These are necessary for pilots who rent aircraft, instructor/check pilots and those who fly infrequently.

Discussion: Pilots who fly infrequently, rent aircraft or require system input changes inflight do not remember the details of system operation and do not normally have access to a manufacturer's manual when they need one. In addition, instructors and check pilots often need a quick reference guide to explain the operation of the system when demonstrating or checking out new pilots in an aircraft. Finally, pilots who fly several

aircraft with a variety of system types need this type of guide to help them remember nuances of each system's software and display protocol.

Nature of Impact: The primary impact of the lack of a checklist type of guide is to discourage system use. The secondary impact is to greatly increase the time and effort involved in obtaining an operator's manual (if available) for the system in the aircraft, looking up the input/output procedures, display options, data base contents, etc. The need for such a checklist was expressed by pilots at all levels from Part 121 air carriers and Part 135 offshore helicopter pilots to corporate pilots and the typical general aviation pleasure pilot. Succinctly stated: "Manuals and pilot guides are not well organized to allow random information access. We have written our own. The routine nature of scheduled flights sometimes allows the pilots to become rusty on all the various features available," (Appendix B, number 18).

Recommended Solution: This problem could easily be resolved by the creation of a Loran-C/GPS checklist type system guide or quick reference handbook that stays with the aircraft and can be used by whoever flies that aircraft on a given day.

3.3.2 Manuals Are Not Adequate

Problem Statement: Manuals are not organized or formatted for ease of use by pilots.

Discussion: The user's viewpoint is that manuals provided by the manufacturers are not clear, are poorly indexed and are difficult to use. In response to the question: What are your major pilot interface concerns? A majority of the pilots interviewed explicitly mentioned manual deficiencies. The written responses varied as follows (Appendix B, numbers 19 - 26 inclusive):

- "What manual?" (ed. This indicates that manuals are not always available)
- "Handbook is not explicit"
- "Installer gives more information than the manual"
- "Manual" (ed. A typical response by 25% of the pilots)
- "Manuals are marketing tools not instructional"
- "Manuals are too technically oriented for most pilot's interest. Too much what & why, not enough how-to. Manuals appear to be written by technicians rather than users."
- "Manuals not readable"
- "Manual incomplete on user instructions for a newcomer"

Nature of Impact: This problem limits the pilot's ability to discover and use all of the functions provided. It also results in lack of confidence and reversion to known systems (i.e., VOR/DME) when workload is high or controllers ask for impromptu position reports or course changes.

Recommended Solution: A standardized, sectionalized system users manual format (like the standard outline for aircraft manuals) should be developed and required for Loran-C and GPS.

3.3.3 Need for Training Tutorials

Problem Statement: Training tutorials are not available to facilitate pilot understanding of the system and expedite its use.

Discussion: Pilots expressed the need for introductory and training tutorial information built into the system for all of the basic functions of the systems. These tutorials should function as a road map that guides the newcomer through system operation and functionality from turn-on and start-up, to operation and use of flight planning, data base use, impromptu changes of data inflight (e.g., waypoint-in-use), etc. The level of detail desired for these tutorials was aptly stated as: "A built-in tutorial is needed to learn the basic features. The tutorial should allow any pilot to turn on a strange Loran-C or GPS system and use it almost immediately from the instructions and prompts on the screen," (Appendix B, number 27).

Nature of Impact: The current lack of the type of tutorial proposed inhibits the use of Loran-C systems for both pilots who own a specific system and pilots who rent or are required to fly aircraft equipped with different systems. This type of tutorial would benefit pilots from both a knowledge and efficiency of use viewpoint. The tutorial would also assist pilots who fly infrequently, rent aircraft, or fly a variety of aircraft equipped with different systems.

Recommended Solution: Manufacturers and the FAA should seriously consider this extremely important suggestion. There is a need for this type of tutorial for all complex navigation and flight management systems. Consideration should be given to both new designs and the estimated 100,000 systems already sold. Possible alternatives to built-in tutorials for the systems in use should be considered such as video-tutorials, PC-based system emulations, interactive training devices, regional pilot refresher courses, etc.

3.3.4 Lack of Curriculum for Instructors

Problem Statement: Instructors generally are not familiar with Loran-C and GPS system operation and cannot provide the necessary information to train pilots to safely operate the systems in the NAS.

Discussion: A major complaint by the pilots interviewed was that instructor's are not familiar with Loran-C or GPS. Some pilots stated that: "The installer gave me more information than the manual or the instructor who checked me out," (Appendix B, number 28). Pilots are not currently able to obtain system use instruction from the manufacturers, the FAA, flight schools, or their local instructors. They, therefore, do not understand how to use the full capability of the systems they have access to.

Nature of Impact: This deficiency combined with the lack of usable manuals, tutorials, etc., has drastically inhibited the utility and use of Loran-C by the active pilots interviewed. The current impact is to use Loran-C or GPS within their limited capabilities, but to revert to VOR/DME or other familiar systems when they cannot use the Loran-C or GPS. This characteristic will be a serious inhibitor to the future use of these systems in the NAS (when VOR/DME is not available) unless some type of formal action is undertaken.

Recommended Solution: An instructor's and check-pilot syllabus and curriculum should be developed to resolve this shortcoming. This syllabus could be used in conjunction with the checklist type of guide or Quick Reference Handbook (suggested in 3.3.1) to provide new Loran-C and GPS users with the needed preflight knowledge and capabilities to operate in the NAS. In addition, an examiner's guide and syllabus should be developed to insure that the instructors retain their proficiency and ability to train the more complex systems.

3.3.5 Removeable Units Are Required

Problem Statement: Pilot training, familiarization, and proficiency with Loran-C/GPS are inhibited when the units cannot be removed from the cockpit.

Discussion: Several pilots commented that they would like to be able to remove the Loran-C system for at-home training. This is not only a convenience issue, but one of practicality and cost since doing all the training and flight planning with the system installed in the aircraft would either run the battery down or consume expensive fuel. Removeable systems would also facilitate cross-training for those pilots using PC-based flight planning software.

Nature of Impact: The major impact of this problem is that pilots are not familiar with or capable of using *most* of the system's features. For example, most did not use the flight planning, turn anticipation, parallel offset, wind aloft input, E6B, or VNAV functions. The primary reason for their inability to use these functions was: "The expense and safety implications of trying to learn the system under the try-while-you-fly concept," (Appendix B, number 29).

Recommended Solution: All units should be removeable for at-home desktop training and flight planning. It is too time consuming and too costly to perform all the necessary training and familiarity with the complete functional capabilities of these systems while installed in the aircraft. The additional availability of a stand-alone training unit with database for use at FBOs who rent Loran-C or GPS equipped aircraft would also increase system use. Pilots could familiarize themselves with the functions, procedures and capabilities during down-time between flights or prior to renting an aircraft equipped with a specific system.

3.3.6 Database Updating

Problem Statement: Database updates are not typically used by the pilots interviewed. This will become a serious problem if/when systems are approved for IFR or approach use.

Discussion: General aviation pilots appreciate and rely on the database for three- and five-letter identifiers to identify waypoints (usually VORs, NDBs, Airports or intersections) for route and flight planning. However, this large group of users does not typically subscribe to updates of the databases on a regular cycle (like the 56-day cycle used by instrument pilots to update their Jeppessen charts). They may or may not update every one to two years. This is not a major problem for today's VMC enroute use. It could be a very serious problem if, or when, these systems are used IFR (especially for approaches). It will become a serious database and situational awareness problem for VFR flight if and when the VOR/DME system is decommissioned as the international standard for civil air navigation. The DOD requirement for and use of VOR/DME is targeted to terminate in the year 2000. Civil use of VOR/DME as a short range navigation system is expected to continue into the next century.

Nature of Impact: Current VFR pilots are navigating with datab ses that may or may not be current. This can cause errors in the waypoint identifier which could impact both navigation and communications with Flight Service Stations (for flight planning) or ATC (for communicating and navigating). VFR, this problem causes higher workload in terms of use of the system and increased communications. If this practice is allowed to continue when these systems are approved for IFR, a safety impact may occur.

Recommended Solution: Pilot education and training are required to impress upon the users the importance of maintaining a current database. Manuals should be clear on how to update and how frequently the database is expected to change. When the database does change, the manufacturer should assume the responsibility for notifying all system owners of the revision and encouraging an upgrade. In the future IFR use, regulatory changes may be necessary to insure pilot's have the most current databases installed prior to using them in the IFR system. In addition, both the Jeppessen and NOAA data bases will need to be updated in a consistent manner. In fact, new chart requirements and update cycles may be necessary for VFR navigation in the NAS when VOR/DME is no longer in use.

4. CONCLUSIONS AND RECOMMENDATIONS

The pilot problems, concerns and limitations in the use of Loran-C and GPS illustrate that the current systems are not straightforward and intuitive to operate. The human factor problems associated with system operation involve input controls, software logic, availability and order of displayed data, and the complexity in using all the functions available. These problems have limited the use of these systems, have impacted operational integration of these systems into the NAS, and may have a safety impact if they remain uncorrected. Therefore, the following conclusions and recommendations are provided to begin the work necessary to resolve the problems identified.

1. A comprehensive study and critical evaluation of multi-function knobs, keys, and switches is recommended. The objective of this analysis should be to identify human memory limits, error frequency and type, workload limits by phase of flight, etc. Once identified and quantified, these results could provide design guidelines or minimum operational performance standards for:

- Number and type of controls (knobs, keys, switches,etc.)
- Number of functions per knob
- Type and sequence of functions

2. A major re-design of system software/function organization should be performed to make Loran-C or GPS systems pilot-friendly and intuitive to operate. The recommended organization would be by flight phase: pre-flight, takeoff, climb, cruise, descent, approach, landing, missed approach, and post-flight. This re-design should include an examination of minimum data required and displayed for each phase of flight organized by pilot action required. In addition, on-screen prompts or a help function should be incorporated for each phase/page of data.

3. Mathematical limits and realistic built-in cross-checks should be developed and implemented to prevent the reversal of latitude/longitude, the input of large E/W or N/S errors (i.e., hemisphere checks), the input of leg or route segment lengths that exceed typical aircraft range limits (i.e., > 999), and other reality checks which will reduce input error potential and enhance both system use and operational safety.

4. Manuals, handbooks and user's guides should be written clearly and concisely and organized in an easy to use fashion. Standardization of the table of contents or outline of these materials (similar to the aircraft flight manual standard outline) was one improvement suggested by the pilots. The importance of random access to flight critical information and functions, as well as ease of use of the large number of functions, should be considered during this rewrite.

5. There is a definite need for a checklist type of guide or quick reference handbook that stays with the aircraft. Both general aviation pilots and Part 135 operators expressed this need since: more than one pilot generally flies each aircraft (seldom does the manufacturer supply more than one manual for each system sold); check airmen and instructors need to

know more than one system; pilots who fly infrequently or rent aircraft need a checklist; and, even private aircraft/system owners need this type of mind jogger information as a ready reference during each flight.

6. Avionics system training should be a requirement for both private pilot licensing and testing. Training and qualification standards need to be developed and implemented for both pilots and instructors using these complex digital systems. Classroom familiarization and instruction on Loran-C or GPS hardware, software, and system operation will be critical to full integration and use of these systems in congested terminal airspace, for instrument flight, and for non-precision approaches/missed approaches.

7. Limited hardware and software standardization guidelines (and Advisory Circular material) should be developed to reduce the GPS human error potential as described by current users of Loran-C.

8. The requirements for additional pre-stored or library data waypoints, fixes, or routes needed to fly Loran-C or GPS on instrument approaches, in congested terminal areas, for holding patterns, or around controlled airspace should be investigated. Specifically, pilot's expressed a need for sufficient library data to navigate around controlled airspace and on VFR fly-ways through congested terminal areas. These suggestions indicate a need for more than one pre-stored route in some areas.

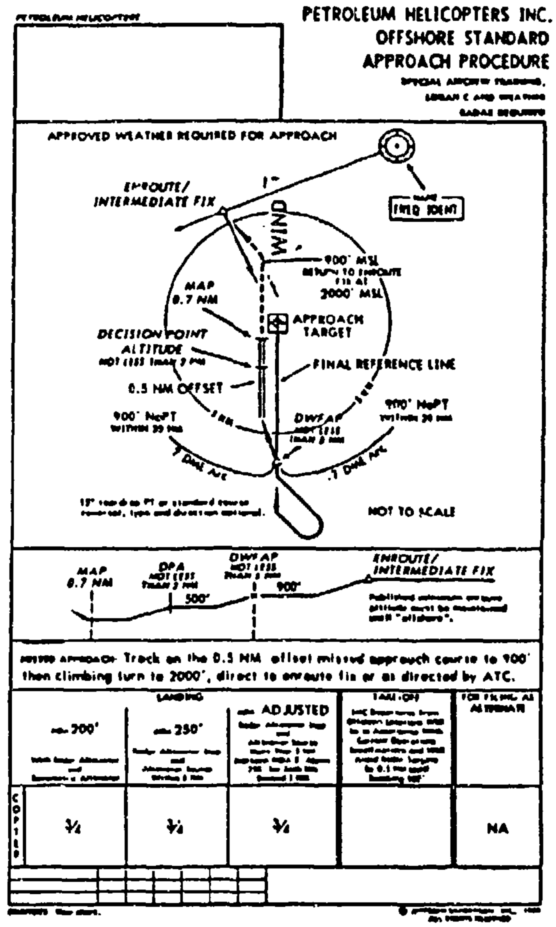
9. The predominant use of the system library of five letter waypoint identifiers to input Loran-C or GPS routes and waypoints requires an investigation of sectional, low-altitude enroute charts and approach plates to determine/evaluate the need for adding identifiers to frequently used fixes, intersections, local fixes, etc. (i.e., those elements of the chart or map for which identifiers are not currently included). For example, many airports have alpha-numeric identifiers that do not appear on the charts and must be looked up with a facilities directory or by spelling out the closest city name on the Loran-C unit. This evaluation should also reconfirm that the system libraries or databases are using the same identifiers as the charts for all published information.

APPENDIX A

OFFSHORE STANDARD APPROACH PLATE

III. OSAP PROCEDURES (Cont.)

C. OSAP CHART



DATE ACCEPTED: OCT 10 1989
Inspector
P.O.I.
FAA - ASW - FSDO - 62 - BTR

Transmittal No. 89-00 (NEW)
August 1, 1989

APPENDIX B

PILOT COMMENTS DURING FOCUS GROUP DISCUSSIONS

1. "Because it is so reliable normally, Loran-C can easily create pilot dependency and complacency."
2. "On our Loran-C set, you have to get too engrossed in instrument for simple functions (i.e., change/enter waypoints)."
3. "Pilots spending too much time inside playing with the Loran when they should be looking for other traffic."
4. "On some models a doctorate degree in computer programming is handy."
5. "Manuals are too technically oriented for most pilots interest. Too much what and why, not enough 'how to'. Manuals appear to be written by technicians rather than users."
6. "Unlabeled, multi-function knobs are confusing and the multiple uses easily forgotten."
7. "The three knobs on my system have 18 combinations of ways to use them."
8. "Why can't the basic direction of the ON/OFF switch or knob be common between systems?"
9. "Warning indicators must be adequate to attract the pilot's attention and prevent deviations."
10. "Selecting the correct mode of operation on this unit is a problem in that it is difficult to remember which page of this massive system contains the information you need. Once you find the correct page, you must remember (or look up) the correct data entry sequence. And in most cases, as with other such modal programs, making a mistake means starting over from the beginning. You'd think programmers had never heard of a backspace key."
11. "The system will accept any error you input. For example, you can input 911 degrees longitude and it will accurately calculate a course to this nonexistent position. You can also enter up to 99 degrees magnetic deviation and it will accept it."
12. "Such a vast amount of information is available that the full extent of the system is very difficult to learn and use."
13. "One or two weeks without flying requires relearning how to use the system. Some on-screen help would increase the usability of these system."
14. "My major concern are the complex procedures for entering waypoints and the head-down time which elapses when programming new waypoint designation."
15. "The manuals do not always keep pace with the software updates."
16. "[The software upgrades] were not made by someone who was familiar with how the systems were used."
17. "Five miles accuracy enroute is fine, but, not reasonable for terminal area or approach use."
18. "Manuals and pilot guides are not well organized to allow random information access. We have written our own. The routine nature of scheduled flights sometimes allows the pilots to become rusty on all the various features available."
19. "What manual?" (ed. Manuals are not always available)
20. "Handbook is not explicit"
21. "Installer gives more information than the manual."
22. "Manual" (ed. A typical response by 25% of the pilots)

23. "Manuals are marketing tools not instructional."
24. "Manuals are too technically oriented for most pilot's interest. Too much what & why, not enough how-to. Manuals appear to be written by technicians rather than users."
25. "Manuals not readable."
26. "Manual incomplete on user instructions for a newcomer."
27. "The installer gave me more information than manual or the instructor who checked me out."
28. "A built-in tutorial is needed to learn the basic features. The tutorial should allow any pilot to turn on a 'strange' Loran-C or GPS system and use it almost immediately from the instructions and prompts on the screen."
29. "The expense and safety implications of trying to learn the system under the 'try-while-you-fly' concept."

APPENDIX C

QUESTIONNAIRE RESULTS

The questionnaire results presented in this section were derived from written pilot responses. Whenever possible direct quotes were used. However, due to the terseness and incomplete sentences provided, editorial comments or a paraphrasing of the actual comments were used in some cases. The pilot comments illustrate both the recurring problems reported by the pilots interviewed and their underlying frustration in trying to use the systems. The answers presented were in response to the following question.

What are your most frequent problems using Loran-C?

The data in this section is divided into two types or categories of users. First, the general aviation pilot community described in Section 2.1 is used as an introduction to the most common problems and concerns of the typical user group. These comments are followed by those of the more sophisticated (Offshore Part 135 and the USCG) Loran-C pilot group comments.

C.1 General Aviation Problems

1. "For me it is the location of the system on the panel -- too far to the right and low -- which often makes the display unreadable if the sun is too strong."

2. "Flying out of the Loran-C navigation TRIAD the system continues to feed information with no warning that it is now unreliable."

3. "Because it is so reliable normally, Loran-C can easily create pilot dependency and complacency."

4. "Training/manuals should emphasize the Loran is not to be used where not authorized."

5. "System failure warnings are hard to see (very small light)."

6. "The database update is too costly."

7. "Loss of signal results in position information which is not always accurate."

8. "The database thinks it is smarter than the pilot" (i.e., it provides more information than the pilot needs and provides it in an order that is not necessarily operationally meaningful).

9. "Precipitation static can cause a warning light which is not easily extinguished."

10. "Databases [on some units] are not easily expandable without having to send them to the factory or buy a new Loran."

11. Training/manuals:
    a. should be easier to use, more readily understandable
    b. *should be able to remove units for desk top training* -- the cockpit is the last place the pilots want to learn the system because of potential distraction, safety, time, and cost involved

12. "The database information is difficult to access."

13. "The keyboard is too sensitive."

C.2 Offshore Part 135 and USCG Problems

These users have operational requirements for parallel offset approaches, search and rescue, etc. that require more of the functions available from the Loran-C systems. Therefore, they use more of the capabilities whether they are formally trained in the system use (USCG) or learn on-the-job (Offshore). However, the latter category of pilots expressed the same frustrations as the general aviation pilot population with the input/output difficulties and lack of training materials. Their responses to the most frequent problems encountered with Loran-C indicate:

1. "The push buttons and knobs are too small for the average pilot."

2. "The small alpha-numerics on most systems are difficult to read."

   "Mistakes entering coordinates are not easily corrected (no backspace key)."

   "Remembering page sequences and data entry procedures is impossible."

5. "The inputs are too difficult to change under single pilot circumstances."
6. Pilots have experienced occasional erroneous data with 2.5 to 4 mile errors at their destination.

7. On some systems, the course change information and groundspeed updating functions are too slow.

8. Erroneous headings have been obtained from the Loran-C system in certain parts of the Gulf.

9. The time delay associated with start up of some equipment was unacceptable.

10. Different Loran systems used by the same pilots in the same geographical area have different co-ordinates for the same waypoint.

11. Station failure and loss of navigation signals have been a problem.

12. "Loran equipment 'looses itself ' (see 11)."

13. "Loran equipment can't 'find itself ' (i.e., cannot re-initialize inflight)."

14. Some Loran-C systems blank out close to thunderstorms.

15. Some Loran-C systems occasionally loose one or more stations.

16. "In this environment (offshore) Loran-C has been unreliable in foul weather."

17. Static build up has caused loss of navigation information for some pilots.

18. Excessive signal noise has caused unusable system outputs when entering clouds/precipitation.

19. Moisture at the antenna causes high noise and system warnings in some cases.

20. "The Loran-C has become lost while enroute and been 'off' 2 or 3 miles."

21. "The CDI needle has locked-up (on some systems) when checking future leg data (e.g. ground speed, ETE and ETA for calculating fuel consumption)."

22. "Moisture in the system either from rain or condensation has interfered with inputs and system operation."

23. "Interference of the Midwest chain with the Gulf chain has caused 3-4 mile course errors" (in the summer of 1991 and continued through October 1991).